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UTILIZATION OF CROP RESIDUES FOR WIND EROSION CONTROL[1]

W. S. Chepil[2]

Dominion Experimental Station, Swift Current, Sask.

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The severe dust storms throughout the semi-arid regions of North America during the years 1931 to 1938 focused the attention of agricultural workers on the problem of preventing erosion of the soil by wind. The general concern over this problem was aroused not because wind erosion was new, for it has occurred throughout many years in the past, but because the extent of the areas involved and the magnitude of the damage was far greater than during any previous period.

Previous to the period just mentioned little attention had been given to the prevention of wind erosion of soil. Particularly in the drier regions, where a large proportion of the cultivated land had to be fallowed each year for reasonable assurance against drought and consequent crop failure, large tracts of land were left bare and unprotected from high winds. Absolutely no attention had been given in many instances to the adoption of methods of farming that would reduce the devastating effects of wind. Throughout many years of production of grain crops the straw was usually removed off the land and much of it burned. Tillage practices likewise were generally such as to leave the soil bare and highly pulverized.

However, major progress in wind erosion prevention and control has been made in recent years through such practices as the development and widespread application of strip farming and the retention of crop residues at the surface of the ground (1, 6, 7). The maintenance of crop residues on cultivated land has been facilitated partly by a substantial increase in the use of combine harvesters which leave all the straw scattered on the land, and partly by considerable progress made in development, improvement, and application of tillage implements that leave all crop residues at the surface of the ground. The widespread utilization of the vegetative litter, commonly called "trash cover" in Canada and "stubble mulch" or "straw mulch" in the United States, is the most promising agricultural development in recent years. Not only has it been of value in overcoming the serious effects of wind, but has proved to be very effective in controlling water erosion, improving the water-holding capacity of the soil, and reducing surface evaporation (5, 8).

Although the beneficial influence of crop residues as a preventive measure against wind erosion has been widely recognized, no information except a preliminary report of the present investigation (4), was available

[1] Contribution from the Experimental Farms Service (P.F.R.A.), Dominion Department of Agriculture, Ottawa. Soils Research Laboratory, Swift Current, Saskatchewan.

[2] Agricultural Scientist.

on the actual reduction of wind erosion produced by different types and quantities of crop residue incorporated in the soil. The purpose of the study reported in this paper was to obtain detailed data on the influence of amount, degree of burial, and nature of crop residue on the erosiveness of different soils. It was hoped that this study would lead to the establishment of some definite numerical relationship between the crop residue factor and wind erosiveness.

MATERIALS AND METHODS

Sixteen widely different soils, comprising 8 distinct morphological types, were used in the experiments. The soils were taken to 4-inch depth from fields of summerfallow containing little or no undecomposed organic matter. For comparison, one sample of Haverhill loam was highly pulverized. In addition to these, clean dune sand, obtained from active dunes, and fresh loam drift were used. The fresh drift represented that portion of the soil which had been moved about by wind over Haverhill loam and deposited against various obstructions. It was composed of erosive particles only and had all the physical characteristics of dry dune sand.

The soils, protected by different amounts of crop residue ranging from 0 to 4 tons per acre, were first thoroughly air dried and then placed in a trough 12 feet long, 21 inches wide and 3 inches high and exposed to a uniform air stream in a wind tunnel. The tunnel had a test chamber 15 feet long, 2.5 feet wide and 2 feet high, equipped with a propeller driven by a variable speed electric motor. The velocity of wind, ranging up to 35 m.p.h., could be easily controlled by a rheostat. All velocity gradients up to 9 inches in height at the leeward end of the exposed area fitted well into Prandtl's logarithmic formula and had all the characteristics of the natural wind up to similar height in the field.

The quantity of soil eroded during each test was determined by weighing the trough with its contents before and after exposure to the wind. In these experiments it was not possible to make accurate determinations of the amounts of erosion less than 0.05 kilograms per square metre of exposed soil. However, this amount of erosion occurring during the first 3 to 5 minutes of exposure to high wind in a tunnel can be considered negligible for all practical purposes.

The soils were exposed to a 17- and a 22-m.p.h. wind as measured at 12 inches above the ground. The former velocity is comparable to a moderate natural wind at which considerable movement of erosive soil becomes apparent, whereas the latter velocity corresponds to a high natural wind, often accompanied by severe dust storms.

Wheat stubble of different lengths and wheat straw that had gone through the threshing machine were the crop residues used. In one case the residue was scattered on the surface, in the other it was mixed into a definite depth of surface soil. In still another case it was anchored by pushing the straw ends or the stubble crowns to 2-inch depth at an angle of 45 degrees with the wind. In the second case about one-half and in the third about five-eighths of the 8-inch stubble was above the surface of the ground.

EXPERIMENTAL RESULTS

The Influence of Strawcover on Wind Velocity and Intensity of Erosion

Figure 1 shows the velocity of wind at different heights over straw covered and bare soil surface, and the relative amounts of soil removed during exposure to a uniform air stream in the laboratory wind tunnel. Large differences in the amounts of eroded soil were entirely due to the type of ground surface, for the structure of the soil was identical throughout the whole series of exposures. The results show that short straw, as it

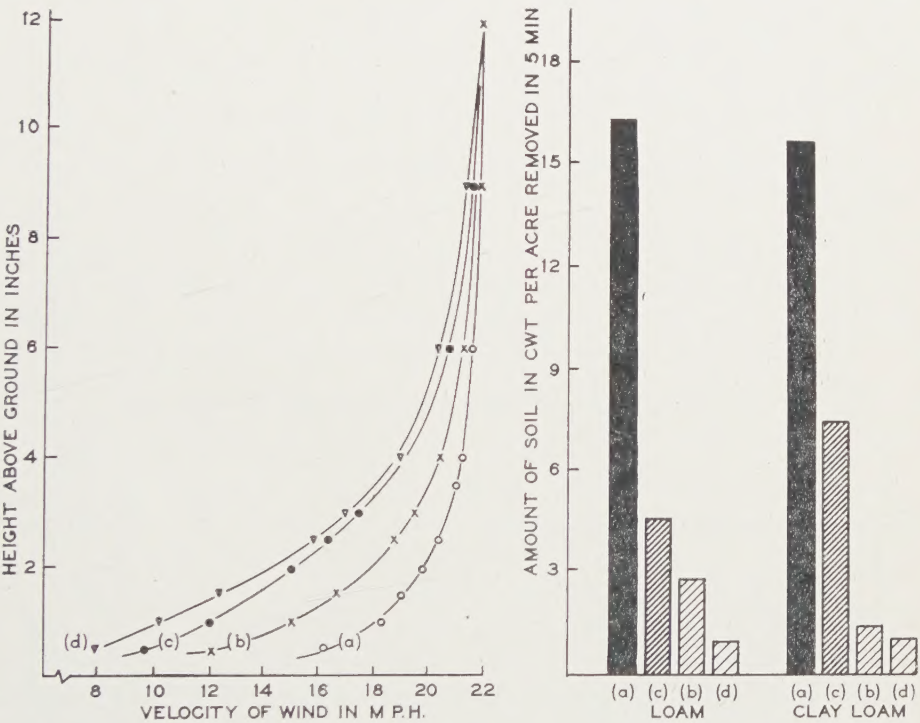

FIGURE 1. Wind velocities at various heights above ground and amounts of soil eroded off (a) a smooth, bare ground, (b) same as (a) with 0.5 ton of wheat straw worked into the surface, (c) ridges 1.25 inches high, 7 inches wide, at right angles to the wind, and (d) ridges as in (c) with straw as in (b).

came from the threshing machine, worked uniformly into the surface to a maximum depth of 2 inches, markedly reduced both the velocity of the wind and the erosion of the soil. The reduction in wind velocity was greatest near the surface of the ground, becoming progressively less with height, and reaching zero at approximately 1 foot of height. Thus, at $\frac{1}{2}$-inch height the velocity over a smooth surface was reduced from 16.1 to 12.0 m.p.h. as a result of mixing one-half ton per acre of wheat straw into the surface of the ground. But at 2 inches above the ground the reduction was only half, and at 5 inches only an eighth of what it was at half-inch height. Somewhat similar, though not as pronounced, reductions in wind velocity were obtained by incorporation of straw to a ridged instead of a smooth soil surface. In other words, the straw was somewhat less

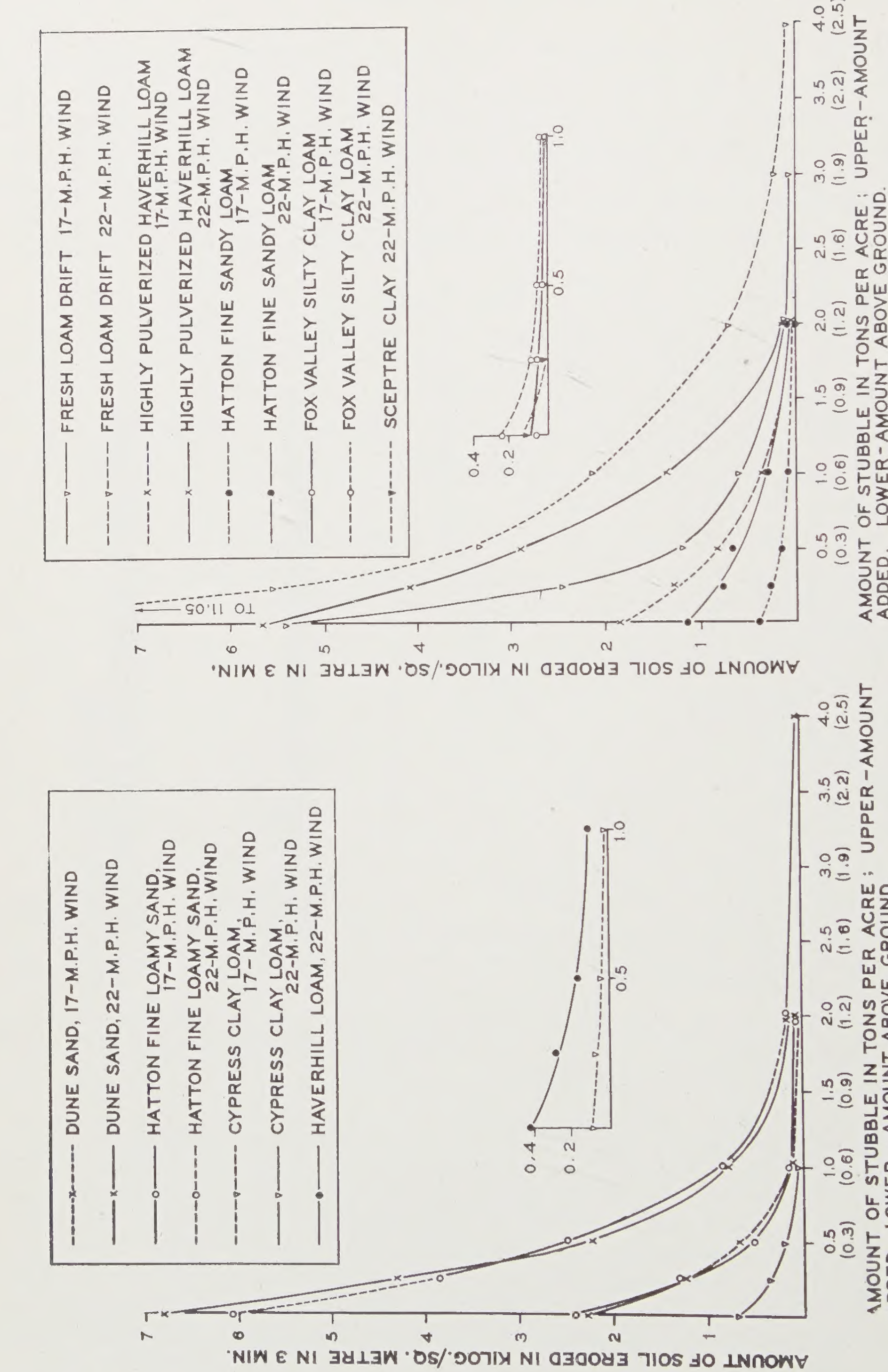

FIGURE 2. Relation between wind erosion and the amount of evenly distributed wheat stubble partially worked into the ground. Eight-inch long stubble was anchored into the soil surface by pushing the crowns down to 2-inch depth at an angle of 45 degrees with the wind.

effective in reducing wind velocity over a ridged than over a smooth surface, but the combined effect of straw and ridges was appreciably greater than the effect of straw or ridges alone.

The effect of the straw on erosiveness was very appreciable on both loam and clay loam soil. Thus, when the amount of soil eroded off a smooth, bare condition averaged 16.2 cwt. per acre during 5 minutes of exposure to wind, that eroded off a smooth, straw covered surface averaged only 2.1 cwt. per acre for the same period. Likewise, when the amount of soil eroded off a ridged, bare surface amounted to 6.0 cwt. per acre, the amount eroded off a similar surface to which straw had been added amounted to 1.0 cwt. per acre for the same period of exposure. In these cases the one-half ton per acre of wheat straw, half of which was above the ground surface, reduced the amount of erosion by 83 and 88%.

The Influence of Amount, Length and Degree of Burial of Crop Residue on Wind Erosion

Figure 2 shows the effect of different amounts of stubble on the erosiveness of 9 widely different soils. It is shown that the intensity of erosion was reduced most markedly by the first increment of stubble added to the soil surface, but each succeeding increment became less and less effective. The relationship between crop residue and the amount of erosion is, therefore, not a linear relationship but a logarithmic type, for when the amount of crop residue is plotted against the logarithm of amount of eroded soil, the curve of erosiveness, as shown in Figure 3, becomes a straight line. It is shown that the slope of the straight line curves is not the same in every case, indicating that the stubble is not equally effective on all soils. The curves for the soils tested indicate that erosiveness q for any given wind velocity can be expressed by

$$q = \text{antilog}_{10}(x - Cy)$$

where x is the logarithm of the amount of erosion of the soil unprotected by crop residue, and which is indicated by the position at which the erosion curves of Figure 3 meet the ordinate, and y the amount of stubble over the surface of the ground. C is a constant which appears to vary somewhat with different soils and, as will be shown later, with the type and actual position of the crop residue above the surface of the ground. In these experiments C varied from 0.8 to 1.8 and, in the units used, had an average value of 1.2.

The amount of stubble required to reduce the erosion to a negligible factor varied greatly with the relative erosiveness of the soil and the velocity of the wind. With the method used to apply the stubble to the surface of the soil, the amount required varied from nearly 0 for highly resistant to as much as 4 tons per acre for very highly erosive soils. This is an equivalent of nearly 0 to 2.5 tons per acre of residue retained above the surface of the ground. On highly resistant samples of Sceptre clay and Fox Valley silty clay loam, from one-eighth to one-half ton per acre was required to withstand a 22-m.p.h. wind as measured at 1 foot height. To withstand the same velocity of wind 0.5 to 1.5 tons per acre were required for moderately erosive samples of Haverhill loam, Cypress clay loam and Hatton fine sandy loam, and 1.5 to 4 tons per acre for very highly

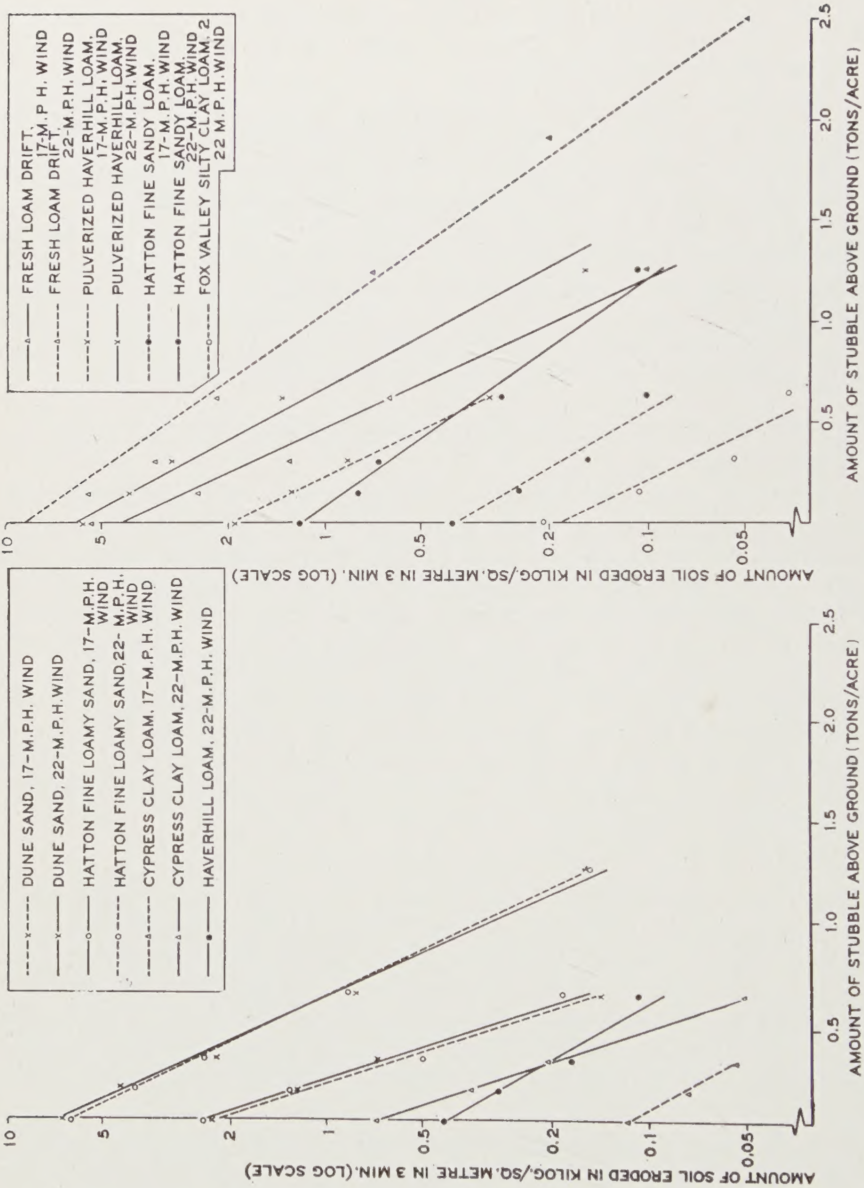

FIGURE 3. Relation between wind erosion and the amount of stubble above the ground.

erosive samples of pulverized Haverhill loam, Hatton fine loamy sand, fresh loam drift, and dune sand. Thus, the greater the erosiveness of the soil the greater was the quantity of stubble required for equal protection. The effectiveness of stubble in preventing erosion of any soil would, of course, depend not on the amount applied, but mainly on the amount retained above the surface of the ground. Figure 4 shows a heavy cover of combine stubble which gave complete protection to soil against highly

FIGURE 4. A heavy cover of wheat stubble and straw on a highly erosive Sceptre heavy clay affording virtually complete protection against wind.

erosive winds. In this case, with the proper use of a suitable surface tillage implement, approximately $1\frac{3}{4}$ tons of stubble per acre were retained above the surface of the ground.

The data further indicate that the higher the velocity of wind the greater was the amount of crop residue required. Thus, 0.5 ton per acre of stubble on Fox Valley silty clay loam under a 17-m.p.h. wind gave about the same degree of protection as 1 ton per acre under a 22-m.p.h. wind. Likewise 1 ton per acre on fresh loam drift under 17-m.p.h. was about as effective as 2 tons under a 22-m.p.h. wind. To give equal protection, therefore, the amount of stubble had to be approximately doubled to withstand the increase in wind velocity of 5 m.p.h. at 1-foot height.

TABLE 1.—THE EFFECT OF LENGTH OF WHEAT STUBBLE ON WIND EROSION

Length of stubble (inches)	Wind in m.p.h. at 12-inch height	Amount of soil in tons per acre eroded when stubble was applied at		
		0.25 ton/acre	0.5 ton/acre	1 ton/acre
2	17	22.6	10.9	3.3
6	17	13.3	6.0	2.7
2	22	84.0	61.4	22.8
6	22	64.7	53.4	13.9
2	27	228.0	170.0	145.0
6	27	174.0	156.0	95.7

Table 1 shows the relative effect of the length of stubble on wind erosion. Under wind velocities up to 27-m.p.h. the shorter stubble afforded less protection than equal amounts of longer stubble. The percentage difference was greatest under a moderately low velocity and least under a very high one. Thus, under a 17-m.p.h. wind the 2-inch stubble was, on the average, 64.5% as effective as the 6-inch stubble, but under a 22-m.p.h. wind it was 75.0% and under 27-m.p.h. 78.0% as effective as the longer stubble.

Table 2.—The effect of degree of burial of wheat stubble on wind erosion

Amount of stubble and method of application	Amount of soil eroded in tons per acre			
	Hatton fine sandy loam		Fox Valley silty clay loam	
	17-m.p.h. wind	22-m.p.h. wind	17-m.p.h. wind	22-m.p.h. wind
None	0.70	3.18	0.48	1.59
0.25 ton, uniformly mixed with 2-inch depth of soil*	0.59	2.40	0.29	1.26
0.25 ton, anchored†	0.45	2.20	0.19	0.83

* Approximately one-half of the stubble remained above the ground surface.

† Eight-inch stubble was anchored by pushing it down to 2-inch depth at an angle of 45 degrees with the wind. Approximately five-eighths of the stubble was, therefore, above the ground surface.

The effect of degree of burial of wheat stubble is indicated in Table 2. The data show that mixing 8-inch long stubble into the 2-inch layer of surface soil was somewhat less effective than merely anchoring the stubble by pushing it down to 2-inch depth at an angle of 45 degrees with the wind. The former treatment is somewhat comparable to a condition that would be obtained with a disk harrow or a one-way disk, whereas the latter may be obtained with various types of subsurface blade implements. In the former treatment approximately one-half and in the latter approximately five-eighths of the stubble was above the surface of the ground. There was, therefore, about 20% less stubble above the ground surface in the former than the latter case. The average difference in the intensity of erosion between the two types of treatment amounted to approximately 20%.

Figure 5 gives further information on the effect of degree of burial of straw and stubble on wind erosion. In this experiment the stubble was 8 inches long, and straw was as it came from the threshing machine and of variable length ranging from a fraction of an inch to 12 inches. In one case the straw or stubble was merely scattered on the surface of the ground, in the other it was partially mixed with the surface soil. In the latter case about one-half of the residue was above the surface of the ground. The data show that under a 17-m.p.h. wind straw scattered on the surface of the ground was slightly more effective in overcoming drifting than when half of it was above and half below the ground surface. Under a 22-m.p.h. wind, on the other hand, most of the straw scattered on the surface of the ground was blown off by the wind, giving little protection to the soil.

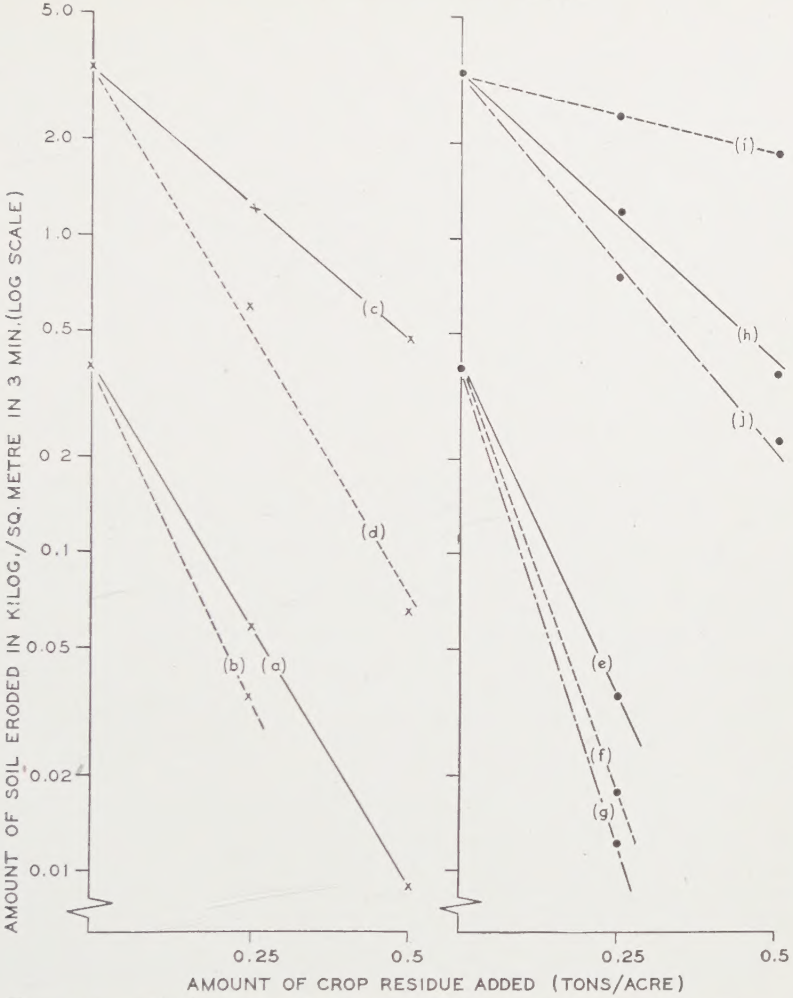

FIGURE 5. Relative effect of wheat stubble and straw on wind erosion; (a) stubble, (b) straw, partially worked into the ground, 17-m.p.h. wind; (c) stubble, (d) straw, partially worked into the ground, 22-m.p.h. wind; (e) stubble, (f) straw, (g) mixture of stubble and straw, scattered on the ground, 17-m.p.h. wind; (h) stubble, (i) straw, (j) mixture of straw and stubble, scattered on the ground, 22-m.p.h. wind.

The results with stubble were entirely different to those with straw. Because of the greater density of the crowns, the stubble was less subject to removal by wind. However, as a result of greater density, and because of the fact that up to as many as 5 culms were held together by a single crown, stubble had less protective surface and failed to cover the ground as thoroughly as an equal weight of straw. When anchored to the surface of the ground the straw was therefore much more effective in overcoming erosion, irrespective of wind velocity. When merely scattered on the surface of the ground, the straw was also more effective than stubble, but only under wind not sufficiently strong to carry much of it away. As soon as the wind reached a velocity of about 20 m.p.h. most of the straw moved off with the wind and left much of the soil surface unprotected. On the other hand, little stubble was moved by a 17-m.p.h. wind and only from one-third to one-half by a 22-m.p.h. wind.

Stubble scattered on the surface of the ground was somewhat more effective in controlling soil drifting than where one-half of it was buried in the ground. The difference was greater under a 17-m.p.h. than a 22-m.p.h. wind, due to the fact that the higher velocity caused greater removal of stubble not anchored to the ground.

When scattered on the surface of the ground, mixtures of equal quantities of straw and stubble were more effective in controlling soil drifting than straw or stubble alone. In these cases, the straw was the effective agent in protecting the soil against wind and the stubble in supplying sufficient anchorage to the straw.

DISCUSSION AND CONCLUSIONS

Results reported in this paper indicate that crop residue retained at the surface of the ground has a very marked effect in preventing wind erosion of soil.

Figure 1 shows that the velocity of wind near the ground was highest over a smooth, bare surface (curve a) and lowest over a ridged surface covered with straw (curve d) and that the amount of eroded soil was in direct proportion to wind velocity. However, the velocity over a level, straw covered surface (curve b) was higher than over a ridged, bare surface (curve c), yet the amount of eroded soil was in inverse order to wind velocity. It is evident that the effectiveness of the straw in preventing the erosion of the soil is not entirely due to the reduction in the surface velocity of the wind, but more particularly to the high capacity of the straw to trap the eroding soil. The effect of straw on the surface of the ground is apparently equivalent to changing the condition of the soil itself in such a way as to increase its resistance to wind erosion.

Information has been obtained to show that the intensity of wind erosion is reduced most markedly by the first increment of straw or stubble added to the soil surface, but additional amounts are proportionately less and less effective. This indicates that relatively small quantities of residue, not sufficient to prevent erosion completely, are valuable in greatly reducing the amount of damage that would otherwise occur (Figure 6).

The data show that on moderately to very highly erosive soils from 0.5 to 2.5 of wheat stubble distributed uniformly above the surface of the ground may be necessary to prevent serious damage from wind. The actual amount, of course, would depend somewhat on the length of stubble and degree of anchorage to the ground.

It is evident that the less erosive the soil, the smaller is the amount of stubble, or straw, required to control wind erosion. Hence, soil cloddiness, moisture content, and roughness of ground surface have an additive effect to vegetative litter in controlling wind erosion. The efficiency of a ploughless fallow method by which crop residues are retained at the surface of the ground is, of course, limited by the amount of residue available. In most of the semi-arid regions of the Canadian prairies good crop growth is by no means assured, and years may occur when insufficient amounts of residue may be available for adequate protection. The use of crop residues should therefore be made in combination with other well recognized control practices, particularly such as strip farming and the maintenance of cloddy and ridged soil conditions.

It is also recognized that the use of crop residues for both wind and water erosion control leaves many problems still unsolved, such as the

effect of relatively large quantities of organic residue on soil structure and fertility, and their relation to insect and plant disease control. Such problems are beyond the scope of this investigation and no attempt will be made to discuss them.

The question of maintaining a crop residue cover for wind erosion control is further complicated by the nature of the soil. Soils that do not retain a cloddy structure cannot, with any degree of safety, be left bare, and should therefore be covered with as much vegetative matter as can be conveniently handled by suitable tillage implements. Some medium textured soils, such as loams, on the other hand, can maintain a cloddy, wind resistant structure, particularly after deep ploughing. Ploughing would bury all the organic residue, but would have a definite advantage in overcoming erosion by wind when insufficient amounts of residue are present to give the soil the necessary protection. The question that must

FIGURE 6. Fallow partially protected from wind by short binder stubble. Due to insufficient anchorage, much of the stubble is blown into heaps. Bare areas have 2 to 4 inches of top soil removed, whereas the protected areas show no removal or slight accumulation of eroded soil.

be answered is whether the influence of increased cloddiness produced by ploughing is greater than the protective value of crop residue that may be retained at the surface of the ground. This and previous investigations (2, 3) furnish some information on the relative effects of crop residue and degree of cloddiness on wind erosion of soil.

It is recognized, that dependence on a cloddy structure alone for wind erosion control is hazardous; hence a crop residue cover and a cloddy structure should be the ideal. A number of new tillage implements have been developed and applied recently with this ideal in mind.

The data indicate that under similar conditions of soil and wind 1 blade of 6-inch long stubble affords more protection to the soil surface than 3 blades of 2-inch long stubble. The reason for this phenomenon is not clear. It is perhaps due to the fact that blades of longer stubble extend

higher in the air than those of shorter stubble, thus causing greater reduction of wind velocity near the ground. In addition to greater protection from longer stubble, cutting the crop as high as possible would have an added advantage of increasing its total quantity, thereby offering still greater protection to the soil. This is particularly important where crops are harvested with a binder.

The type of crop residue and the degree to which it is buried in the soil are also of great importance. When stubble is buried, as with a plough, its protective value is eliminated. Various forms of blade implements have recently appeared on the market which are designed to destroy weeds and at the same time maintain crop residues on the surface of the ground. The information obtained from this study, however, indicates that scattering the crop residue on bare ground may not give as much protection against wind as if it is scattered on and anchored to the ground by partial mixing with the surface soil. This is especially true for light organic materials such as straw, but not for heavier materials such as stubble. Straw scattered among the stubble, as with a combine, affords an almost ideal type of cover for wind erosion control. In such cases the stubble provides the necessary anchorage to the ground, and the straw the more thorough protection to the surface.

SUMMARY

Results of wind tunnel experiments indicating the effect of wheat stubble and straw on the erosiveness of 16 widely different soils are outlined.

It was found that crop residue retained at the surface of the ground has a very marked effect in reducing wind velocity and erosion of the soil. It is shown that the effectiveness of organic residue in preventing wind erosion is partly due to the reduction in wind velocity, but more particularly to the high capacity of the residue to trap the eroding soil.

The amount of wheat stubble or straw required to prevent erosion varied greatly with the relative erosiveness of the soil and the velocity of the wind. For soils and velocities used, the amount varied from nearly 0 to 2.5 tons per acre of stubble retained above the surface of the ground.

The higher the velocity of wind, the greater was the amount of crop residue required. To give equal protection the amount of stubble had to be doubled to withstand an increase in velocity of 5 m.p.h. at 1-foot height.

Short stubble afforded less protection to the soil than an equal amount of longer stubble.

Stubble afforded less coverage to the ground than an equal weight of straw, but was less subject to removal by high winds. When scattered on the surface of the ground mixtures of straw and stubble afforded more protection against wind than equivalent amounts of straw or stubble alone.

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THE USE OF *DROSOPHILA MELANOGASTER* MEIG. FOR COMPARING THE TOXICITY OF STOMACH POISON DUSTS[1]

F. T. Lord[2]

Dominion Entomological Laboratory, Annapolis Royal, N.S.

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The problem of the blueberry maggot, *Rhagoletis pomonella* (Walsh), became acute in Yarmouth County, N.S., several years ago, so that control work became imperative if the industry were to escape serious damage. A considerable amount of field work has been performed with both power and hand dusters, resulting in a fair degree of success. The habits of the blueberry maggot fly and the nature of its environment, however, make a direct comparison of poison treatments impossible in the field. It is also a difficult insect to handle in the laboratory. A technique was therefore devised by which preliminary tests of various insecticides could be carried on with the pomace fly, *Drosophila melanogaster* Meig., which offers many advantages as a laboratory insect. Some parallel tests were also run with blueberry and apple maggot adults, which, while not conclusive, indicated that their reactions to some of the common poisons were similar to those of the pomace fly. No claim, however, is made that any of the results obtained with *Drosophila* are necessarily applicable to the maggot flies.

METHODS EMPLOYED

The flies to be tested were confined in a lantern globe, where they were supplied with water from a wick and food from a section of honey-treated paper, which was previously treated with dust in the manner described below. Each day all the globes were examined, and the flies removed and the sex determined.

Method of Rearing Flies

Flies for these tests were reared on a mixture of mashed boiled potatoes and one Royal yeast cake in cloth-covered cages as described by Stultz (4), but with the modifications made by Lord (2).

The flies were aged in a cloth-covered cage until three days old, being fed meanwhile by means of a wad of absorbent cotton moistened with a 5% solution of honey. This was placed in a petri dish with a slight excess of honey solution in the bottom to maintain the moisture content of the cotton. During the morning of the third day the flies were placed in the lantern globes containing the materials to be tested.

Preparation of the Globe

The top of the lantern globe was covered with a piece of good quality cheesecloth (B, Figure 1), that had stapled in the centre a perforated square of light cardboard (b_1, Figure 1), which was stoppered with a cork after

[1] Contribution No. 2279, Division of Entomology, Science Service, Department of Agriculture, Ottawa, Canada.
[2] Junior Entomologist.

the globe had been charged with flies. When the treated microscope slide (D, Figure 1) described below had been fastened into place, the bottom of the globe was covered with a cloth (C, Figure 1) holding a strip of blotting paper, (c_1, Figure 1) $1\frac{1}{4}$ by 6 inches, stapled into a slit in the cloth and reinforced with two small strips of waxed cardboard (c_3, Figure 1). This cloth with the attached wick was then fastened to the bottom of the globe by means of a ring of thin brass wire and the prepared globe was then set into an 800 ml. beaker filled to within an inch of the brim with water. The wick served to supply moisture for the flies and food was obtained from the honey-treated slide.

The bottom cloth had been previously soaked in a gasoline solution of paraffin wax to prevent absorption of moisture from the wick into the cloth.

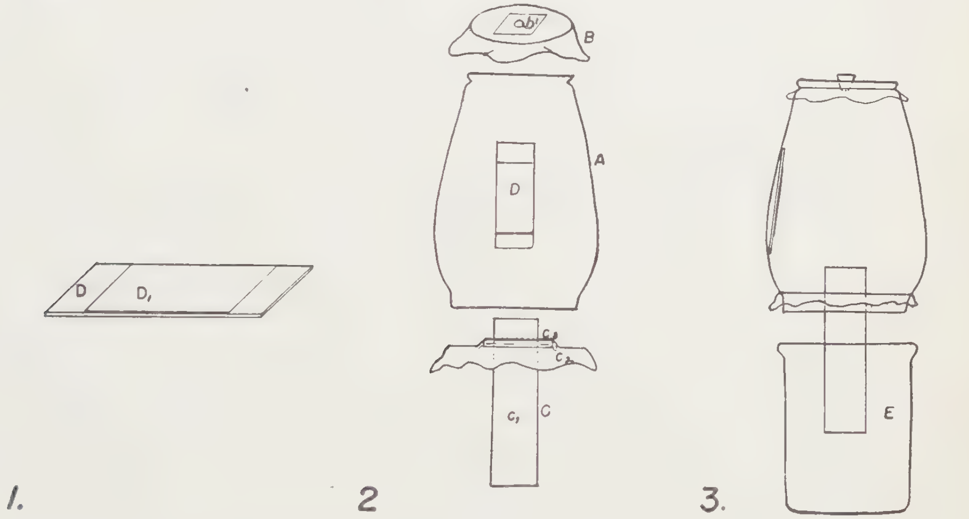

FIGURE 1.

Preparation of the Microscope Slide Bearing Food Material

Preparatory to making up the slides, white blotting paper was soaked in a 50% honey solution and then carefully dried, care being taken to keep the moisture evenly distributed while drying. A 50% solution of honey seemed to be about the maximum concentration that could be used and still ensure a non-sticky surface upon drying. This treated paper was then cut into rectangular strips 1 by 2 inches and glued to glass microscope slides. These were later coated with dust in a laboratory duster described by Payne and Stultz (3). A bell jar was used in place of the 4-sided chamber in this device, and in later experiments the whole device was discarded in favour of the more elaborate apparatus described by Heuberger and Turner (1), which is much better suited to the dusting of slides. The latter device also eliminates trouble from static electricity as well as allowing much greater control over the amount of dust deposited per slide. It is hoped that further investigation will reveal methods whereby the dosage per slide can be predetermined. The dusted slides have to be handled quite carefully to avoid jarring the dust loose while they are being attached to the walls of the lantern globe with strips of cellulose tape.

Method of Placing Samples of Flies in the Globes

In charging the globes it is necessary to take precautions to have representative samples of the fly population in each globe. The flies were collected into a gum jar, the top covered with a piece of cotton, and when they crowded to the light side they were easily dislodged into a heap in the bottom of the jar. The male flies seemed to be able to get out of the mêlée more readily than the females so it was necessary to dislodge the flies into a heap and quickly remove the desired sample with an aspirator. Usually three globes were used per material tested. To ensure an even distribution of the samples of flies, all the globes in a series of tests were charged at random. In this way the three globes in which any one material was being tested were never charged consecutively.

TESTS UPON THE TECHNIQUE EMPLOYED

The dead flies were removed each day, the sex determined and the results recorded. In removing the flies there is grave danger of the operator drawing up small amounts of poison from the bottom of the globe if a *mouth suction type of aspirator* is used. A certain amount of dust is dislodged by the flies in feeding upon the slides and although the amount of poison in the bottom of a globe is not great, the amount absorbed after removing the flies from 80 or more jars every day would probably reach formidable proportions.

Influence of the Kind of Food

Although previous experience with feeding *Drosophila* adults had revealed that they will live for a considerable length of time on either honey or cane sugar solution, a series of tests was initiated to determine which material was best suited. A number of filter papers (approximate area 6.4 square inches) were thoroughly soaked in solutions of the two materials and tested in the lantern globes.

In this case, where there was a large feeding surface and a small number of flies, it will be noted in Table 1 that the average length of life is much longer than it was in subsequent tests, where 2 square inches of paper was used with a larger number of flies. It is also very apparent that honey is a somewhat better food material than cane sugar.

TABLE 1.—INFLUENCE OF CONCENTRATION OF HONEY OR SUGAR ON THE LONGEVITY OF *D. melanogaster* ADULT*

Paper treated with	No. flies per globe	Average longevity in days	
		Male	Female
50% honey	47	36.7	39.4
50% sugar	60	31.5	34.3
25% honey	75	20.0	24.5
25% sugar	107	11.7	13.5
12.5% honey	73	6.7	9.8
12.5% sugar	83	2.2	3.5
6.2% honey	108	2.0	3.3
6.2% sugar	101	1.4	3.1

* Approximate area of filter papers 6·4 inches.

Influence of Amount of Feeding Surface per Fly

It is not possible with the present technique to place a predetermined number of flies in any globe, so 3 series of globes were charged with the aim of having too few flies, a sufficient number, and too many flies respectively. The globes also contained two concentrations of honey and two areas of treated paper. Duplicate globes were prepared in each case. The results are shown in Table 2.

TABLE 2.—INFLUENCE OF THE NUMBER OF FLIES PER GLOBE, CONCENTRATION OF HONEY AND AREA OF TREATED PAPER ON THE LONGEVITY OF *D. melanogaster* ADULTS

Concentration of honey	Area of treated paper	Flies per globe	Average longevity		Average	
			Male	Female	Male	Female
%	sq in.	no.	days	days	days	days
50	2	50	20.4	21.5	20.9	22.1
50	2	48	21.6	22.3		
50	2	107	16.1	17.2	16.1	17.4
50	2	98	16.2	17.5		
50	2	197	11.2	12.3	11.8	12.8
50	2	154	12.6	13.4		
50	1	44	15.7	17.3	16.5	18.0
50	1	34	17.3	19.1		
50	1	107	12.4	13.0	10.7	12.3
50	1	77	8.4	11.2		
50	1	216	6.7	7.7	6.9	7.7
50	1	156	7.1	7.7		
25	2	48	9.6	11.0	9.5	10.9
25	2	50	9.5	10.7		
25	2	165	7.3	8.1	7.1	8.2
25	2	83	6.9	8.4		
25	2	208	6.5	7.2	6.1	7.0
25	2	221	5.6	6.8		
25	1	56	8.0	9.2	7.2	8.3
25	1	50	6.4	7.2		
25	1	114	7.0	7.8	6.3	7.1
25	1	81	5.3	6.2		
25	1	237	5.7	6.7	4.9	5.9
25	1	183	3.9	4.9		

It is apparent that the number of flies per globe, the concentration of honey, and the amount of treated surface all have an important bearing on the results. The figures are quite uniform but in all cases the average is somewhat lower than has been the experience in other tests.

Influence of Age of the Prepared Slides

As there are a number of operations involved, each time-consuming, in preparing a series of tests, it is often necessary to make the slides up

1 to several days before the tests are started. It was therefore important to know if any change took place in the food value of the prepared slides. A number of slides were prepared from time to time and stored in a dry closet and then all slides were tested at the same time. Two square inches of honey-treated paper was used.

The slides do not deteriorate greatly with age, as is shown in Table 3. Those made up during the few days prior to testing seemed to result in somewhat greater longevity of the caged flies but these differences are slight and do not seem to be significant.

TABLE 3.—INFLUENCE OF THE AGE OF THE SLIDES ON THE LONGEVITY OF *D. melanogaster* ADULTS IN LANTERN GLOBES

Age of prepared slide	Globes tested	Total flies used	Average longevity	
			Male	Female
days	no.	no.	days	days
68	3	243	23.1	29.4
29	3	244	21.0	25.5
23	3	303	25.6	27.9
18	3	289	22.5	26.9
10	3	288	27.7	29.5
5	3	349	23.0	24.9
4	3	253	25.5	25.6
3	3	301	26.7	30.1
2	3	278	28.2	29.2
1	3	279	28.6	29.8
Day of test	3	262	29.7	31.4

Influence of Dust Film on the Slide

The diluent used in a dust may possibly form a mechanical barrier to prevent the flies from obtaining sufficient food, so this point was examined experimentally by dusting slides, treated with 25% honey solution, with supposedly inert materials. The results are shown in Table 4.

TABLE 4.—INFLUENCE OF MATERIALS USED IN DUST MIXTURES ON THE LONGEVITY OF *D. melanogaster* ADULTS IN LANTERN GLOBES

Material	Flies per globe	Average longevity		Average	
		Male	Female	Male	Female
	no.	days	days	days	days
Talc	117	13.4	14.7	13.9	15.0
Talc	92	15.5	16.7		
Talc†	121	13.0	14.0		
Walnut shell flour	118	13.3	14.4	13.3	15.0
Walnut shell flour	106	13.2	14.6		
*Walnut shell flour†	132	13.0	14.1		
*Walnut shell flour†	123	14.4	16.5		
Check	85	17.2	18.4	15.0	16.1
*Check†	122	13.4	14.2		

* Two square inches of filter paper treated with 25% honey solution.
† Slide dipped in water and excess quickly shaken off just before dusting.

The influence of the dust film did not seem to be a very important factor but the results were not conclusive.

RESULTS OF SOME TOXICITY TESTS

A considerable number of materials were tested by the methods described above and some typical results with some common poisons are given. The results in Table 5 are from slides which were dusted in the Payne and Stultz (3) duster. Those in Table 6 are from slides treated in the Heuberger and Turner (1) duster.

TABLE 5.—LONGEVITY OF *D. melanogaster* ADULTS WITH SLIDES DUSTED IN PAYNE AND STULTZ (3) APPARATUS*

Material	Globes	Total flies	Average longevity	
			Male	Female
	no.	no.	days	days
Lead arsenate alone	3	191	6.7	7.5
Lead arsenate—hydrated lime	3	266	8.1	8.9
Lead arsenate—gypsum	3	235	6.3	6.8
Lead arsenate—sulphur	3	300	7.7	8.1
Lead arsenate—talc	3	215	6.6	7.5
Lead arsenate—walnut shell flour	3	308	6.9	7.8
Lead arsenate—calcium arsenate	3	235	4.9	5.8
Calcium arsenate alone	3	284	3.4	4.3
Calcium arsenate—hydrated lime	3	317	4.4	5.3
Calcium arsenate—gypsum	3	266	3.7	4.6
Calcium arsenate—sulphur	3	307	3.4	4.3
Calcium arsenate—talc	3	262	3.4	4.4
Calcium arsenate—walnut shell flour	3	280	3.4	4.2
Synthetic cryolite alone	3	207	5.8	6.1
Synthetic cryolite—hydrated lime	3	262	9.9	10.6
Synthetic cryolite—gypsum	3	260	4.7	4.7
Synthetic cryolite—sulphur	3	295	6.5	7.7
Synthetic cryolite—talc	3	271	6.3	7.4
Synthetic cryolite—walnut shell flour	3	298	6.3	8.7
Sulphur alone	3	406	17.9	18.1
Check	3	239	23.3	27.3

* Amount per charge, 0.5 gm. of mixtures; .025 gm. of undiluted poisons. All mixtures 50 : 50.

The diluents used seemed to have little influence on the speed of toxic action except in the case of gypsum which appeared to have a slight adjuvantal value with both lead arsenate and cryolite. With synthetic cryolite as a dust, hydrated lime seemed to have a very deleterious effect.

Increasing the copper sulphate content of the copper sulphate-lime series appeared to have little or no influence in decreasing the longevity of the caged flies. With the copper sulphate-lime-calcium arsenate series variation in the deposit of dust seemed to be more closely related to the differences in longevity than did the amount of copper sulphate used in the mixtures. It did not appear that copper-lime dust as a diluent had much influence on the toxicity of calcium arsenate.

TABLE 6.—LONGEVITY OF *D. melanogaster* ADULTS WITH SLIDES DUSTED IN HEUBERGER AND TURNER (1) APPARATUS

Proportions of materials	Deposit dust per slide	Probable deposit cal. arsenate	Flies used	Average longevity	
				Male	Female
	gm.	gm.	no.	days	days
Copper sulphate–calcium arsenate–hydrated lime†					
5–30–65	.0023	.0007	228	7.9	10.8
10–30–60	.0041	.0012	254	7.1	9.0
15–30–55	.0038	.0011	278	7.1	9.1
20–30–50	.0030	.0009	311	6.8	8.5
25–30–45	.0026	.0008	332	7.2	9.1
Copper sulphate–hydrated lime†					
5–95	.0026		196	24.4	26.2
10–90	.0043		275	21.9	24.5
15–85	.0059		250	16.3	19.0
20–80	.0067		218	16.1	18.7
25–75	.0065		282	15.0	17.6
Calcium arsenate	.0017		341	5.6	7.3

* Amount per charge, 0.5 gm. dust. Dust settling for first 30 seconds discarded. Slides exposed during next 5 minutes.

† Monohydrated copper sulphate.

SUGGESTIONS FOR IMPROVEMENT IN THE METHODS DESCRIBED

There are several important factors which need investigation, the results of which may necessitate some fundamental changes in the methods described:

1. It is important to know more about the influence of the amount of poison per slide on the longevity of the flies.

2. Methods for placing a predetermined dosage of dust on the slides should be worked out.

3. When the above points have been investigated, series of tests should be run in which the poisoned slides are removed and replaced by unpoisoned slides after any desired interval of feeding.

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CONTROL OF WATER-CORE OF TURNIPS BY SPRAYING WITH BORAX[1]

J. D. MacLachlan[2]

Ontario Agricultural College, Guelph, Ontario

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The table turnip (rutabaga) is an important cash crop in western Ontario. More than 2 million bushels of the 1942 yield were shipped to the United States market, alone.

Water-core or Brown Heart is one of the most troublesome diseases with which the growers must contend. This physiological disorder is caused by a deficiency of boron, and its presence renders the turnip unsaleable for table use. The extent of water-core in the various turnip districts varies from year to year but the loss from this disease, for other than stock feed, has been estimated as high as 20% in some years. The recommendations for soil application of borax to control this disorder have not been generally adopted; too many failures have been met. In one experiment at the Ontario Agricultural College, borax was applied to the soil in amounts sufficient to be toxic to certain succeeding crops (100 lb. per acre) and yet no control of water-core was obtained. The high lime content of the soil is a likely contributory agent to failures of soil applications of borax to control the disease.

The investigations herein reported gave evidence that the required amounts of boron can be applied, in a practical manner, to the turnip plant, by spraying the leaves with an aqueous solution of borax. An abstract of the earlier phases of this investigation has already been published (1).

INVESTIGATIONS

Experimental

An extensive series of small plot experiments were carried on during 1940 and 1941 to determine if foliage spraying with borax would control water-core. From these experiments a promising spray schedule was obtained. It was found that a 2% aqueous solution of borax (approximately saturation in cold water) could be used without causing foliage burning; that spraying the upper surfaces of the leaves was adequate but the inclusion of a spreader was necessary; and that two sprays would prevent water-core, the first when the roots were 1 to 2 inches in diameter, the second, approximately 1 month later.

In 1942, spraying for the control of water-core was tested in 12 turnip fields in the neighbourhood of Guelph, Ontario. These fields were on farms where water-core had been severe the previous year. Plots, 6 rows wide and about 75 ft. long, were established in 11 of these fields. A 5-gallon knap-sack sprayer was used to apply a 2% borax solution with $\frac{1}{4}$% liquid Orvus (Procter and Gamble, Toronto) added as a spreader. Just

[1]Contribution from the Department of Botany.

[2] Associate Professor of Botany.

prior to the time of harvesting, 5 samples, each of 10 consecutive turnips in a row, were cut from the unsprayed portions of the field immediately bordering the 4 sides of each sprayed plot. If a significant amount of water-core was present, then 5 similar samples were cut from various areas within the sprayed plot. Of the 11 fields in which spraying was done in this manner, 5 contained sufficient water-core in the checks to give an index of the control obtained by spraying. The remaining field, consisting of about 2 acres of turnips, was completely sprayed with the exception of interspersed checks of 3 rows each. A 40-gallon 4-row potato sprayer with 1 nozzle per row turned down on the foliage was used in this instance. Water-core was prevalent in the checks at the time of harvesting and 10 samples, similar to those described above, were cut from various portions of sprayed and unsprayed rows, respectively.

Table 1.—The control of water-core of turnips obtained by spraying the leaves with borax

Field	Soil type and turnip variety	Root diameter		Turnip quality at time of harvesting	Water-core incidence					
					Unsprayed areas			Sprayed plots		
		1st spray	2nd spray		None[1]	Mild[2]	Severe[3]	None	Mild	Severe
		in.	in.		%	%	%	%	%	%
A	Clay loam Purple King	1-1½	4-6	Black rot and soft rot prevalent	70	14	16	100	0	0
B	Sandy loam Purple King	1	2-5	Very large, rough; stock feed only	54	6	40	100	0	0
C	Sandy loam Laurentian	1-2	4-5	Grade A	38	18	44	98	2	0
D	Sandy loam Canadian Gem	1	2-4	Grade A	18	8	74	98	2	0
E	Light sandy loam Laurentian	2-3	—	Stunted, woody	6	32	62	96	4	0
F	Sandy clay loam Laurentian	1-1½	2-4	Grade A	25	20	55	100	0	0

1. None—no water-core present.
2. Mild—minor indications of water-core but still saleable.
3. Severe—unsaleable because of water-core.

Information concerning the 6 fields in which significant amounts of water-core occurred in the checks is presented in Table 1. Sample portions of fields A to E were sprayed with the knap-sack sprayer while field F was sprayed with the 4-row potato sprayer. As may be seen from this table, practically complete control of water-core was obtained regardless of severity of water-core in the checks. Moreover, the soil type, turnip variety, and turnip quality at the time of harvesting did not influence the degree of control obtained. In one instance (field E) control was obtained with a single spray, applied at a stage of turnip development approximately intermediate between that of the 2-spray schedule on the other fields. The control obtained on field F indicated that the 4-row potato sprayer was a satisfactory means of application.

Commercial Application

A considerable acreage of turnips was sprayed on a commercial basis, during 1943, throughout widely scattered districts of western Ontario. Records were obtained from 42 farms involving about 250 acres of turnips. The following spray formula was used: Borax 2% (8 lb. to 40 gal. of water) or saturation in cold water where the farmer mixed the spray in a separate barrel and always kept some undissolved borax in the bottom of the barrel after each refill; bentonite clay, 2 lb. to 40 gal. of water, as a sticker; and liquid Orvus, ½ pint to 40 gal. of water, which was usually decreased in amount in successive spray-tank loads because the Orvus tended to accumulate as froth in the tank. In all instances the upper surfaces only of the leaves were sprayed. In most cases a 40-gallon, 4-row, potato sprayer with 1 nozzle per row was used. However, some used large orchard sprayers with either a gun or boom attachment while others improvised sprayers of devious kinds. The most efficient equipment observed was that of a tractor with a spray tank mounted on a platform over the rear axle and a 4-row boom attached behind the front wheels. No appreciable damage to the turnip foliage was caused by any of the spray equipment; a rubber-tired tractor caused the least damage.

The spray schedule on different farms varied somewhat owing in part to the limited amount of spray equipment and to labour shortage. Some applied the first spray when the roots were 1 to 2 inches in diameter but did not apply the second spray 1 month later. Others attempted to reduce the schedule to 1 application by spraying when the roots were 2 to 4 inches in diameter; this was suggested by the control obtained in one field during 1942 (See Table 1, field F).

The variation in spray schedules provided useful information with respect to future recommendations. In several instances, where the spray was not applied until the roots were 2 to 4 inches in diameter, a few of the larger turnips developed water-core. In 2 fields the spray was applied after water-core was already present and no control whatever was obtained. It is important, then, that the spray be applied a considerable length of time prior to the normal inception of water-core. Practically complete control was obtained in all instances where the initial spray was applied before the largest turnips had reached a diameter of 2 inches.

Many of the growers who sprayed before the roots had reached a diameter of 2 inches obtained complete control of water-core with a single application. That a second application of spray (approximately 1 month later) is sometimes necessary was illustrated on one farm where the turnips have always been severely affected by water-core. Adequate checks were left in a 4-acre field on this farm when the initial spray was applied. One month later these checks showed more than 50% water-core while none could be found in the sprayed areas. A second spray was applied leaving a small portion of the field with only the initial spray. At the time of harvesting almost 100% of the turnips in the unsprayed checks were affected by water-core, more than 50% of the turnips in that portion of the

field which received only the initial spray were affected by water-core, while the remainder of the field which received the 2 sprays was completely free of water-core.

In one field considerable water-core developed in a few rows which were sprayed just as it was beginning to rain; the rest of this field was free of water-core. Therefore, the spray should have an opportunity to dry on the leaves prior to a rain.

In spite of the variation which occurred in the spray schedule, the control of water-core obtained was, on the whole, outstanding. It was difficult to obtain quantitative data on the effectiveness of the spray because many farmers left either inadequate, or else no checks at all. However, on 7 farms involving 46 acres of turnips adequate checks were left and these contained such a high percentage of water-core that it was obvious the entire fields would have been condemned had they not been sprayed. In these 7 instances, practically complete control was obtained by spraying. In no instance did any appreciable amount of water-core develop where the spray was applied in the proper manner and at the proper times.

CONCLUSIONS AND RECOMMENDATIONS

Spraying the leaves of turnips with a solution of borax will supply sufficient boron to the plants to give practical control of water-core. The cost of materials is less than $1.00 per acre, per spray, which is a cheap rate of insurance in those areas where soil applications of borax fail to give results. Spraying is simplified by the fact that it is not necessary to spray the under sides of the leaves. Any type of spraying machine can be used so long as a uniform coverage of the upper surfaces of the leaves is obtained. No appreciable mechanical injury to the leaves occurred from the wheels of a 4-row potato sprayer or a commercial orchard sprayer whether drawn by horse or by tractor.

Further investigations will be carried on during the coming season with respect to the use of various stickers and spreaders as well as the possibility of using a borax dust rather than an aqueous spray. In the meantime the following spray program is submitted as an effective and practical means to control water-core of turnips:

Dissolve borax at the rate of 8 lb. to 40 gal. of water or else use a saturated solution of borax in cold water. To this add bentonite clay at the rate of 2 lb. to 40 gal. of borax solution. If the bentonite clay is soaked in water over night at the rate of 1 lb. of clay to a pail of water it will mix more readily. Screen this mixture into the spray tank, add $\frac{1}{2}$ pint of liquid Orvus and stir gently. The amount of Orvus may be decreased somewhat in succeeding tankfuls because it tends to accumulate as froth in the tank. Forty gallons of spray is sufficient for an acre of turnips.

The first spray should be applied when the roots are 1 to $1\frac{1}{2}$ inches in diameter but not more than 2 inches in diameter. This one spray is sufficient to prevent a mild to moderate occurrence of water-core but not always for a severe occurrence. Since it is impossible to predict the severity to which water-core will develop, 1 or 2 check blocks should be

left in each acre of turnips preferably on or over the face of a knoll, or where water-core is most liable to be severe. A check block 8 rows wide and about 25 ft. long is adequate to allow for wind drift of the spray. If no water-core has developed in these check blocks a month after the first spray, the chances are that the second spray is not necessary. If, however, water-core is present in these checks, a second spray should be applied.

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FLOUR, A SUBSTITUTE FOR BRAN IN GRASSHOPPER BAIT[1]

L. C. PAUL[2] AND K. M. KING[3]

Dominion Entomological Laboratory, Saskatoon, Sask.

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One of the most outstanding of the developments contributing to the progress of grasshopper control in North America has been the steady cheapening of the unit cost of poisoned bait without lessening its efficiency. In 1920, using the Kansas formula with bran the sole carrier and with citrus fruits and molasses as attrahents, the aggregate cost of material plus freight in Saskatchewan averaged $90.00 per ton (dry weight). In contrast, the bait used in that province since 1938 has averaged only $11.00 per ton, and yet is equally efficient under the majority of conditions encountered. This greatly reduced rate of cost has been fundamental to the enormous growth of grasshopper baiting campaigns.

To this development, Saskatchewan has made a considerable contribution. It is the purpose of this paper to outline the steps taken in this province and the work on which the decisions were based.

In the modification of bait formulae in Saskatchewan (Vigor (5, 6, 7)), four major stages are recognizable. In 1921 the carrier was changed from all bran to equal volumes of bran and sawdust. From 1921 to 1923, attrahents were gradually modified and eventually eliminated. In 1932 Saskatchewan pioneered in the adoption, for the entire campaign, of liquid sodium arsenite as the poison in place of powdered white arsenic. In 1938 flour as a substitute for bran in an extensive campaign was used first in this province. The flour-sawdust carrier has been used for all subsequent Saskatchewan campaigns, and has also been adopted elsewhere.

PRELIMINARY WORK OF 1934-37

The first specific attention by the present writers to the use of bran substitutes in grasshopper baits was given in 1934. Then, as a result of the impending bran shortage and the prospects of bran prices increasing, experimental work was undertaken in co-operation with the Saskatchewan Department of Agriculture. The purpose of the study was to examine all likely bran substitutes with a view to producing an effective bait at a lower cost. This involved consideration of the efficiency of the materials, their general and local supply, availability and market price, as well as whether they could be employed with the standard mixing station equipment or would require special processing such as passing through a hammer-mill. At that time the following materials were investigated: No. 4 Northern Hard red spring wheat, both coarsely and finely chopped; No. 1 wheat, coarsely and finely chopped; rolled wheat; "Blackhawk," a commercial preparation resembling finely chopped oats; oat hulls; oat chop; rolled

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[1] Contribution No. 2289, Division of Entomology, Science Service, Department of Agriculture, Ottawa, Canada.

[2] Assistant Entomologist in charge of grasshopper investigations.

[3] Officer-in-charge of Laboratory.

oats; barley chop; alfalfa meal; ground flax; peat moss, one-quarter inch mull; horse manure (Criddle's mixture formula); and shorts; together with the following materials which were put through a hammer-mill: wheat straw, oat straw, alfalfa, sweet clover and wild slough hay. Seasoned and fresh sawdusts, both unscreened and finely screened, were also compared. The mixing, absorptive, and spreading qualities of numerous formulae were tested.

The most promising bran substitute indicated by this preliminary work was ground wheat, particularly low grade wheat. This was cheap, widely distributed and in ample supply. The formula of 25% ground wheat and 75% sawdust by bulk absorbed as much or slightly more water than the "standard" bait of 50% bran and 50% sawdust.[4] At the above proportion coarsely ground milled wheat spread well, but finely ground wheat tended to "ball up."

Cage tests with early instars of *Melanoplus mexicanus mexicanus* (Sauss.), *Camnula pellucida* (Scudder) and *Melanoplus bivittatus* (Say) indicated that bait with coarsely ground wheat at the proportions of 1 : 3 of sawdust by volume was just as efficient as the standard, each averaging 87.5% kill in four series (mean difference—nil, standard error 7.0). The two series with finely ground wheat produced results that did not differ statistically from the standard bait (mean difference 15%, standard error 21.4). In these preliminary cage tests, neither the age nor the texture of the sawdust appeared materially to affect its efficiency. The peat moss bait of equal volumes of moss and sawdust, although very absorbent and in efficiency equal to the standard bait in the single series tested, had several undesirable features. The peat moss was very dusty when dry and thus unpleasant to work with. It would absorb so much water that, unless great care was taken in mixing, the water would run off excessively when the bait was piled or bagged. In carload lots, moss and bran were about equal in cost.

Following the preliminary investigations of 1934 on bran substitutes, no experiments were conducted until 1938, as it had proved possible to secure sufficient bran at a reasonable price for the provincial control campaigns. During the interim, however, there were a few opportunities to observe the effectiveness of milled or ground wheat and of shorts.

DEVELOPMENTS OF 1938

After the extremely severe drouth of 1937, when no crops were harvested over a large portion of the prairie area of Saskatchewan, bran was so scarce that immediate search for a bran substitute was urgent. Commencing in March 1938 further investigations were started by testing the mixing qualities and water holding capacities of the more promising bran substitutes, including milled wheat, flour, ground screenings, and ground

[4] Throughout the experiments reported in this paper bran and sawdust in equal volume has been used as the standard carrier for checking the comparisons. In all baits, both in investigations and in campaigns, the poison used was liquid sodium arsenite, 8 pounds of As_2O_3 per gallon, used at the rate of 1 quart of poison solution to 100 pounds of bran or equivalent volume of carrier.

millet. On the basis of these and previous experimental data and field observations in Saskatchewan, together with parallel investigations conducted by Dr. J. R. Parker and his staff in the United States Bureau of Entomology and Plant Quarantine, this Laboratory recommended to the Saskatchewan Department of Agriculture that bran be replaced by ground or milled wheat, with all parts retained, or by low grade flour at the ratio of 1 part to approximately 13 parts of sawdust by volume. In practical terms this was stated as 3 gallons to 40 gallons, a volume which was suitable for the standard mixing machines; or, in large quantities at the proportion of $1\frac{1}{2}$ to 2 tons of flour for each carload of sawdust. At this stage wheat was recommended in preference to flour. The low grade wheat, particularly durum wheat, was cheaper than low grade flour, and offered fewer difficulties when mixed by inexperienced operators. With improved mixing technique and the heavy demands for bait in June, flour largely replaced the wheat. However, all field control officers who had experience with both the ground wheat and flour preferred the former because of the better mixing and spreading qualities resulting from its high proportion of bran. Nevertheless, with flour as well as with ground wheat very satisfactory kills were reported by farmers and field control officers alike. This seems especially significant since there were none of the popular complaints of ineffectiveness that so often come with any new bait, especially one known to be cheaper.

Immediately after grasshopper hatching commenced in 1938, bait experiments on field plots were begun at Radisson, Saskatchewan, with the following baits: standard bait, low grade flour and sawdust 1 : 9; finely ground No. 3 durum wheat and sawdust 1 : 13; and apple peelings—sawdust 1 : 3. These baits were prepared and spread by hand on half-acre plots. Both the spreading of the bait and the collecting of grasshoppers were alternated between the two investigators V. L. Berg and W. B. Fox, to minimize the personal element. The spreading was done at the rate of approximately 10 lb. of bait (dry weight) per acre. Three hours after spreading, three cages, each containing approximately 100 grasshoppers, were collected from each baited plot and an unbaited area. Each day the hoppers were fed fresh vegetation and after 72 hours the mortality was determined. The net mortality, i.e. corrected for natural mortality which occurred among unbaited grasshoppers was then calculated; (the collections reported in Tables 1, 2 and 3 averaged 57%, 52% and 54% dead, respectively). The cages were $5\frac{1}{2}$ inches square by 12 inches high with a wooden base and top, the latter having a $3\frac{1}{2}$ inch hole fitted with cover; the sides were of galvanized wire screen, 14 mesh to the inch. This type, which was adopted from the United States Department of Agriculture, proved satisfactory and has been used throughout our work.

The 1938 results from 6 series of field tests with *Melanoplus mexicanus* and *Camnula pellucida* nymphs and adults are shown in Table 1. These experiments confirmed the general appraisal of bran substitutes throughout the campaign, namely, that milled or ground wheat and low grade flour produced mortalities which did not differ statistically from those of the standard bait.

TABLE 1.—STATISTICAL ANALYSIS OF 1938 BRAN SUBSTITUTE BAIT TESTS

Bait	No. cages	Mean diff.	Standard error	t Value
		%		
Apple vs. standard	18	18.2	6.25	2.917*
Low grade flour vs. milled wheat	18	3.8	1.90	2.000
Standard vs. milled wheat	18	5.9	3.18	1.853
Standard vs. low grade flour	18	2.4	4.43	0.534

* Statistically significant, i.e. 5% point.
(Baits which produced the higher average mortality are placed first in each pair.)

It will be noted that apple peeling bait 1 : 3 was significantly better than the others in 1938. However, this was not the case in 1939 (Table 2) when the proportion was 1 : 9. No further work was done with apple peelings because of their cost and inadequate volume of supply.

FURTHER FIELD EXPERIMENTS, 1939-40

Further experiments with bran substitutes were conducted in 1939 and 1940. in co-operation with the Dominion Entomological Laboratory, Brandon, Manitoba. The 1939 experiments were carried out at Lyleton, Manitoba, by H. W. Moore and W. B. Fox, and in 1940 at Eastend, Sask., by R. H. Handford, L. G. Putnam and D. S. Smith. The statistical analysis of the 1939 data is summarized in Table 2, and the 1940 data in Table 3. In the 1939 and 1940 experiments both the milled wheat and the low grade flour were used in the proportions 1 : 13.

TABLE 2.—STATISTICAL ANALYSIS OF 1939 BRAN SUBSTITUTE BAIT TESTS

Bait	No. cages	Mean diff.	Standard error	t Value
		%		
Analysis of aggregate data on *M. mexicanus* and *C. pellucida*				
Milled wheat vs. low grade flour	24	6.2	2.66	2.351*
Standard vs. low grade flour	24	4.5	2.47	1.839
Standard vs. apple	24	2.3	1.44	1.614
Milled wheat vs. standard	24	1.7	2.12	0.806
Analysis of *M. mexicanus* data				
Standard vs. apple	12	4.5	2.30	1.959
Standard vs. low grade flour	12	3.1	3.08	1.000
Standard vs. milled wheat	12	2.8	2.88	0.981
Milled wheat vs. low grade flour	12	0.2	3.08	0.081
Analysis of *C. pellucida* data				
Milled wheat vs. low grade flour	12	12.2	3.67	3.337†
Milled wheat vs. standard	12	6.2	2.60	2.409*
Standard vs. low grade flour	12	6.0	3.95	1.520
Standard vs. apple	12	0.2	1.62	0.105

* Statistically significant. † Highly significant.
(Baits with the higher average percentage kills are placed first in each pair.)

From the analysis in Table 2, based on 4 series of tests with each species, it is evident that the bran substitutes gave kills which did not differ statistically from the standard bait; except that with *Camnula pellucida* the milled wheat was superior to the standard. When the milled wheat bait was compared with the baiting containing low grade flour, however, the milled wheat bait was superior both in the tests on *C. pellucida* and in the aggregate data.

In view of the rather conclusive data from the previous experiments and campaigns the flour-sawdust bait was given only relatively minor attention in the 1940 experimental bait program. The data (Table 3), though limited and restricted to *M. mexicanus*, confirm the previous findings. Further confirmation is provided in the co-operative experiments of 1941 and 1942, not here reported (Handford (1), Handford and Putnam (2)), as well as in the campaigns of those years.

TABLE 3.—STATISTICAL ANALYSIS OF 1940 BRAN SUBSTITUTE BAIT TESTS

Baits	No. cages	Mean diff.	Standard error	t Value
		%		
Milled wheat vs. standard	6	6.0	7.32	0.820
Standard vs. low grade flour	9	1.4	3.66	0.393
Milled wheat vs. low grade flour	3	1.0	14.16	0.001

(Baits which produced the higher average mortality are placed first in each pair.)

MIXING TECHNIQUE

In preparing a grasshopper bait with flour and sawdust, somewhat greater care is required than with the bran mixture. Experience has shown, however, that with practice the flour-sawdust bait can be prepared both easily and quickly. The points to be watched are: uniform mixing and securing the correct proportion of liquid in each batch. If the flour and sawdust are dumped together into the mixer, the bait tends to ball up badly, especially when the sawdust is already quite wet. From such uneven mixes poor kills may result. No difficulty is encountered however, if the sawdust is put in first and the flour then sprinkled in from end to end with the machine in operation. This does not involve any material increase in time to prepare each mix. There may be wide variations in the absorptive capacity of sawdusts, i.e., seasoned vs. fresh sawdust, as well as in the actual moisture content of the sawdust prior to mixing. Therefore, the correct amount of water to be added must be determined by the mixing station operator for each new shipment of sawdust.[5] The strength of the poison solution must be similarly adjusted according to the water holding capacity of the carrier, since the liquid poison and water are combined for each batch before adding to the mix. If excess water is added it will run off, carrying with it some of the flour and poison; besides weakening the bait this run-off is a hazard to livestock. On the other

[5] Under experimental conditions, thoroughly dried sawdust had to be slightly moistened before adding the flour to prevent the flour from sifting through to the bottom of the mixer. However, this has never been a problem in mixing stations.

hand it is important that the bait be given all the moisture it will absorb, especially since the absorptive power of sawdust is smaller and slower than that of bran. The quantity of water can be safely increased if the bait is allowed to stand for some hours and undue pressure is avoided either in bagging or piling.

SAVINGS

Even before bran substitutes were in general use, the mere knowledge that satisfactory experimental results had been secured is authentically reported to have kept down the market price of bran. According to one of the shrewdest and most experienced field men, this saved the province $3.00 per ton on bran in 1934. On that basis the saving for that year alone was $44,000.

In 1938, the use of ground and milled wheat and of low grade flour instead of bran resulted in a saving of at least $40,000, according to calculations supplied by S. H. Vigor, in charge of purchasing supplies for the grasshopper campaigns. The latter figure is based only upon the prevailing price of bran. Had substitutes not been used, it is certain, considering the very scanty supply, that the price of bran would have advanced materially. It seems evident, therefore, that the real savings were considerably in excess of that figure.

The relationships are best revealed by comparing actual bait-material costs exclusive of transportation, as the latter varies with location of outbreak. In the three years preceding the introduction of flour, 1935 to 1937, inclusive, the average was $14.50 per ton (dry weight). From 1939 to 1942, when flour was used exclusively, the average was $7.40 per ton which was only 51% of the previous cost. This marked reduction in cost was due almost entirely to the change in bait formula rather than to variations in the unit cost of materials in different years (Table 5).

The cost of transportation, however, is also an important consideration. The greater the proportion of sawdust in the bait the more important becomes the freight costs for this item, especially when the source of supply is far from the grasshopper infested area. The effect of this on the relative costs of the two types of bait is illustrated in Table 4 by comparing two districts in which extensive campaigns have been necessary. Robsart represents the maximum sawdust haul (575 miles) and Rosthern one of the shortest (175 miles) in this province. For this comparison, the calculations are on the assumption that the campaign was conducted exclusively in either one or the other district. In 1939 the figure for bait tonnage used in the entire province was employed, while for 1940 the calculations are for the materials actually used in the general Robsart area which had the most severe grasshopper outbreak ever recorded in Saskatchewan. The actual saving in 1939 was approximately $88,000.

These calculations show that, including transportation as well as materials, the total costs for the flour-sawdust bait were only 51% to 65% of the costs which would have been incurred had the bran-sawdust bait been used. The difference between the long and short sawdust haul is seen to be no more than 3 or 4%.

TABLE 4.—RELATIVE COSTS OF BRAN-SAWDUST AND FLOUR-SAWDUST BAITS IF DELIVERED ENTIRELY AT ROSTHERN OR AT ROBSART

—	Total costs		Ratio	Estimated saving	
	"Bran" bait	"Flour" bait			
			%		%
1939					
Rosthern	$228,700	$138,700	61	$90,000	39
Robsart	235,500	152,400	65	83,100	35
1940					
Rosthern	74,700	38,500	51	36,200	49
Robsart	76,800	41,500	54	35,300	46

Besides the saving in the cost of materials the flour-sawdust bait reduces heavy carry-overs from one year to the next, as frequently occurs with bran. Flour is required in such relatively small quantities that it can readily be obtained and trucked in case of emergencies, while it takes comparatively little storage space. Another feature of this bait is that with its high proportion of sawdust it is less attractive to livestock than bait which is half bran.

DISCUSSION

The continued research in grasshopper baits by all workers has resulted in great progressive reduction of the cost of bait with little or no loss of efficiency. The savings thus represented—which, incidentlly, are many times greater than the costs of such research—have had a very important influence upon both the general and administrative acceptance of grasshopper control.

Parker (3) found that the inclusion of citrus fruit, as in the Kansas grasshopper bait formula, was not warranted. Further economies have since been obtained by the introduction of the 1:1 bran-sawdust bait in place of baits in which bran was the only carrier. The present paper has carried on this idea by showing that the still cheaper 1:13 flour-sawdust bait as used in Saskatchewan is equally effective. Some actual savings in this province from the changes of formulae have been presented.

The economic and administrative significance of these progressive developments may be readily seen from Table 5, which shows the *relative* costs of baits used at different periods. Since the costs per dry ton are based upon the average price of each material for the entire 1920-42 period, the influence of changes in bait formulae upon campaign costs is clearly shown. The average cost per ton in 1938-42 represents a 78% reduction from the figure for 1920-23 and 45% from that for 1932-37. The latter saving was entirely attributable to the substitution of flour-sawdust for bran-sawdust as the poison carrier.

TABLE 5.—INFLUENCE OF CHANGES IN BAIT FORMULAE UPON CAMPAIGN COSTS

Basis of comparison	Comparable costs per ton	1934 campaign	All campaigns 1919-42 incl.
1. At 1920-23 rate	$35.18	$817,600	$3,155,900
2. At 1932-37 rate	14.23	330,700	1,276,500
3. At 1938-42 rate	7.89	183,400	707,800
Difference between 1 and 3		634,200	2,448,100
Tonnage (dry weight)		23,240	89,700

Had it been necessary to use the expensive 1920-23 bait formula throughout all these years, it seems definite that in 1934 no province-wide campaign would have been undertaken, in view of the scale of the outbreak and the severe economic depression. In that case losses would have been tremendous. On the other hand, had the present flour-sawdust bait been developed by 1934 it would greatly have eased the administrative decision and financial burden. Even regardless of cost, had an all bran bait been in use in 1934, it seems certain that sufficient material would not have beén available. The quantity of bait actually used in 1934 was nearly one-third greater than the total tonnage for the entire 1919-23 series of campaigns.

Although the general cheapening of baits has indeed been fundamental to the enormous growth of grasshopper control campaigns, not only in Saskatchewan but also in other parts of North America, there is no reason to suppose that the ultimate has yet been reached in this respect. For example, further experiments in co-operation with the Brandon Laboratory (Handford and Putnam (2)) indicate that only 1 volume of flour to 27 of sawdust may be as effective as the 1:13 flour-sawdust bait; although with the greater proportion of sawdust, its age may be an increasingly important factor. It should be kept in mind that the critical figure is that of cost per acre. Thus it may eventually be possible (e.g. Paul (4)) to achieve a lower net cost by the use of a bait which, even if costing more per ton, produces effective kills at much lower rates of application and under a wider range of conditions. Further economies and more effective grasshopper control can be obtained by a careful farm program which includes the judicious use of tillage together with timely and proper spreading of bait. The unit cost of bait, however, will always remain an important element.

SUMMARY

The data presented show that a grasshopper bait in which the carrier consists of 1 part by volume of low-grade flour to 13 parts of sawdust has given equally as good kills as the more expensive bait of equal volumes of bran and sawdust, under conditions representative of the northern Great Plains; liquid sodium arsenite was the poison used with both carriers, with no other ingredient except water in suitable proportions. It is shown that because of its efficiency, availability and low cost, the flour-sawdust bait has since 1938 been used almost exclusively in Saskatchewan, where it was first adopted on a campaign-wide scale. The minimum savings in this province, resulting from this step, have averaged approximately 45%. In the major campaign of 1939 this represented a sum of about $88,000.

The aggregate savings have had an important bearing upon the administrative aspects of grasshopper control. Some other advantages of the bait are brought out, as well as the main precautions which must be observed to ensure its full efficiency.

ACKNOWLEDGMENTS

The writers consider that great credit is due to S. H. Vigor, Field Crops Commissioner, Regina, for assuming the considerable administrative responsibility involved in being the first to use the flour-sawdust bait in a major campaign. Mr. Vigor also at our request calculated the relative costs shown in Table 4. Throughout our work the Saskatchewan Department of Agriculture has closely co-operated by supplying materials and facilities and by making observations of results.

We are indebted to Dr. R. H. Handford of the Dominion Entomological Laboratory, Brandon, Manitoba, in co-operation with whom the grasshopper bait experiments of 1940 to 1942 were conducted, for the analysis presented in Table 3.

Dr. J. R. Parker and colleagues of the United States Bureau of Entomology and Plant Quarantine have been generous in their interest and frank in discussions of mutual problems.

Assistance in the experimental work here reported was given by V. L. Berg, W. B. Fox, H. W. Moore, L. G. Putnam and D. S. Smith, to whom we desire to express our appreciation.

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LIFE HISTORY STUDIES OF THE PEA MOTH, *LASPEYRESIA NIGRICANA* (STEPH.), ON THE GASPE COAST[1]

A. D. Baker, and J. P. Perron[2]

Dominion Department of Agriculture, Ottawa.

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In the first paper of this series (2), of which this is the second, the history and distribution of the pea moth, *Laspeyresia nigricana* (Steph.), in Canada was outlined. In the present paper the records of several years observations on the life history of this insect in Bonaventure County, on the Gaspe Coast, Province of Quebec, are presented. (A summer laboratory was located at St. Godfroi in 1936-38 and at New Carlisle in 1939-42. These two places are about 12 miles apart on the coastal range facing the Bay of Chaleur, and the climatic conditions are very similar.) An attempt is also made to compare these data with all other recorded observations on the life cycle of this insect that have been published by other workers in Canada and the United States.

In Canada at least, accurate information on the life history of the pea moth has been greatly needed for some time. While studies of the life cycle of the insect in other countries may give an approximation of what to expect in this country, such information requires careful checking under more local climatic conditions. As the climatic reactions of any species may vary considerably between one continent and another and between different regions of the same country, it is necessary that these data should be obtained from the particular region in which control studies are being carried out. Accumulation of such information also tends to add to the general sum of knowledge of the reactions of the species to different environmental conditions. Accurate knowledge of the life cycle of the pea moth is found to be of particular significance when one is faced with the problem of formulating adequate control measures.

With most life history studies the use of the calendar in attempting to pin down the time factors between the various stages of development of an insect species is convenient, popular, and has some definite value. However, it is recognized that seasonal conditions may vary greatly from year to year and hence a calendar index is not always a reliable basis for the timing of control measures. Correlations of the stage of development of the host plant, the development of other plant growth, weather conditions, etc., with the critical stages of development of the insect species are frequently useful and important. These methods are used whenever feasible by the economic entomologist, but the relation of the significant stages of development of an insect to the calendar can not yet be completely disregarded in such studies. In the present paper a calendar index is used, but the different events in the life cycle of the insect have also been linked with other events wherever any significance was observed.

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[1] Contribution No. 2291, Division of Entomology, Science Service.

[2] Assistant Entomologist and Agricultural Assistant, respectively.

In a general way the life history of the pea moth bears some resemblance to that of the codling moth. Like the latter insect, the pea moth hibernates as a caterpillar within its cocoon and the adult moths are on the wing the following year about the time their host plants are in bloom and the fruit beginning its development. With both insects, knowledge of the period of adult emergence and oviposition is of considerable importance if insecticidal methods of control are to be of any value. In addition, the present popular methods of pea moth control by clean-up and soil cultivation are both based on accurate knowledge of other phases of the life cycle, such as the period of emergence of the larvae from the pea pods, time of pupation, etc.

LIFE HISTORY

Adult Emergence

The first record on adult emergence in this country appears to have been made by Fletcher in 1897 (5) when he records finding a pea moth adult on July 12. The following year (6) he found the first pea moth on July 13. In both these years the last moth he observed appeared on July 15. From our present knowledge of this insect this total emergence period recorded by Fletcher appears much too short, and may possibly represent the period of peak emergence. Fluke (9), working in Wisconsin, records the first adults as appearing on July 14 and July 12 in 1920 and 1921. In the former year Fluke found the peak of emergence as occurring on July 18 and saw the last adult on July 30. In the latter year the last adult was observed on August 5. Studying this insect in Nova Scotia during the summer of 1918, Brittain (3) records pea moths emerging from July 12 to August 7 (but comments on the presence of a partly grown larva being found in a pea pod on July 18 and several others on July 21). In 1919 he found the first adult on July 12. Hanson and Webster (11) studied the life cycle of this insect in the State of Washington and in 1936 recorded an adult emergence period extending from June 1 to July 25 with maximum emergence occurring around the first two weeks of July. They also record the presence of a partial second generation of moths that "started to emerge late in July and continued through the fall."

The growing season of 1936 on the Gaspe coast was later than the average and as our pea moth studies in these regions were incepted at this time, adult emergence was determined by periodic search for the moths around the developing pea vines of the St. Godfroi district. The first adults were observed on Tom Thumb peas near Shigawake on July 18 and on Tall Telephone peas at St. Godfroi on July 19. However, by July 20 moths were quite numerous throughout the entire St. Godfroi district and it is quite likely that the first moths were flying some time before the first dates recorded. In this year the last adult was seen on August 15. In the autumn of 1936 experimental soil plots were seeded with pea moth larvae and the process repeated each year thereafter so that more definite records of adult emergence were obtained in the years 1937-41. During these years the first pea moth adults were recovered on the following dates: 1937, June 25; 1938, June 10; 1939, July 9; 1940, July 4; and 1941, June 30. The peaks of emergence were as follows: 1937, July 17-21; 1938, July

19-25; 1939, July 24; 1940, July 15; and 1941, July 30. The last moths appeared on the following dates: 1937, July 24; 1938, August 4; 1939, August 13; 1940, August 8; and 1941, August 21. The total emergence period extended for 30, 56, 36, 36, and 53 days, respectively. Fluke's (9) records show an emergence period of 48 days in Wisconsin, Hanson and Webster (11) one of 54 days in Washington, and Brittain (3) one of only 27 days in Nova Scotia.

The charts which appear at the end of this paper show the relationships of sunshine, temperature, and precipitation to the emergence of pea moth adults during the seasons of 1937-40 on the Gaspe coast. In this connection it will be observed that bright and warm spells usually preceded the maximum emergence of the moths. Precipitation is apparently also an important factor in pea moth emergence, particularly when it follows a bright warm period. It must be remembered that the cocoons, containing the hibernating pea moth larvae, lie as a rule only a short distance beneath the soil surface and thus should be easily influenced by even slight precipitation as well as changes in air temperature and light intensity. Instead of precipitation tending to retard emergence our records indicate an assisting action for this function. Thus it may be generally stated that the emergence of the pea moth adults tends to follow a bright and warm period of weather, and this emergence is assisted, or even accelerated, by an adequate supply of moisture.

The chart of adult emergence presented by Fluke (10) would indicate a steady and rather rapid rise in the number of emergents from the time the first adult appears until the peak of emergence is reached. However, the conditions recorded by Hanson and Webster (11), in this regard, are more nearly in conformity with our own findings. Adults may be appearing for as long as 2 or 3 weeks before the main peak of emergence has been reached. This factor needs consideration when chemical control is contemplated and also when the value of planting early varieties of peas is under consideration.

As a general rule Tall Telephone peas are usually coming into full bloom about the time of maximum emergence of pea moth adults. However, as pointed out above, quite a number of adults may be on the wing before this time of pea blooming. It thus is evident that all the moth adults do not have their time of emergence at all well correlated with the development of their cultivated host plant. On the other hand, the time of blooming of some of the wild host plants of the pea moth is usually earlier than that of cultivated peas. From this it might be assumed the early emerging pea moths are tending to conform to the stage of development of the wild hosts and not of the cultivated host plant. The ability of some of these early emerging adults to produce offspring which attack the stems and buds of the pea plant before blooming has occurred has already been recorded by Perron (14).

The period of adult emergence is spread over many weeks, lasting at least a month and sometimes as long as 6 to 8 weeks. However, a main peak of emergence is usually rather well marked, although, in some years, this peak may be spread over a number of days.

Preoviposition Period

Fletcher (7) apparently noticed the presence of a preoviposition period for the pea moth in 1900 when he makes the observation that he did not think that the moth always lays its eggs in the very early stages. Fluke (9) found that "about 3 days after the first moths emerged egg deposition began," and Brittain (3) records a preoviposition period of 4 to 7 days and states that mature eggs were found in the female 3 days after emergence. On the Gaspe coast it was found that the preoviposition period may be as short as 4 days and as long as 8 days. Weather conditions prevailing at the time of moth emergence or immediately thereafter appear to shorten or lengthen the preoviposition period. The normal time between adult emergence and the beginning of oviposition seems to be around 5 to 6 days.

Egg Laying

In 1898 Fletcher (6) recorded pea moth eggs laid after the middle of July, and in 1905 (8) that the eggs were laid on young pea pods as soon as they were formed. Fluke (9) in 1919 found the first eggs on July 17, the greatest number on July 19-20, and the last ones on July 31. Hanson and Webster (11) found eggs laid during June, July, and August. Brittain (3), in 1938, reported egg laying as occurring during the last 3 weeks of July and the first week of August.

Searching for the eggs of the pea moth in the field is an exacting task as they may be laid on any part of the pea plant above the ground, as well as on blades of grass, etc., in or around the pea fields. Their wild host plants are also usually abundant and in bloom during this time. Coupled with these conditions is the fact that the eggs are small and inconspicuous. Thus some natural reservations accompany our data on this point. On the Gaspe coast the first eggs were observed on the following dates: 1936, July 26; 1937, July 11; 1938, July 16; 1939, July 15; 1940, July 4; and 1941, July 8. Our records show the peak of egg laying to have occurred around the following dates: 1936, July 27; 1937, July 26; 1938, July 29; 1939, July 31; 1940, July 20; and 1941, August 4. Egg laying usually tapers off to end around the middle of August but has been observed ending as early as August 1 (1937) and as late as August 23 (1936 and 1941).

Egg Maturity Period

The time required between oviposition and hatching of the eggs is recorded as 7 to 10 days by Fluke (9), 7 to 8 days by Cameron (4), 8 days by Hanson and Webster (11), and only 2 to 3 days by Brittain (3). When the eggs are first laid they are whitish in colour, but by the end of the 2nd to 3rd day this has changed to a reddish tinge which deepens steadily until about the 6th to 7th day. Just a day or so before the eggs are ready to hatch small black spots are visible through the egg shell. Hatching was found to occur around 6 to 8 days after oviposition, although shorter and longer periods have been observed (5 to 9). Hatching of the eggs may be quite rapid and has been timed at 90 seconds for the complete operation. The young larva is usually quite active from the moment of emergence.

Larval Development

According to our records the first larvae noticed in the pea pods were: 1936, August 2 (late season); 1937, July 29; 1938, July 23; 1939, July 28; 1940, July 9; 1941, July 17. The peak of infestation in peas usually occurred during the first two weeks of August, with injury becoming more and more pronounced thereafter.

Fluke (9) recorded the larval period as 16 to 26 days in 1920 and 10 to 27 days in 1921 (10). Miles (12) found the duration of the larval stage in England as 22 days, while in Latvia, Ozolo (13) determined the larval period as 17.5 days at 20° C. (68° F.) and 65 days at 11° C. (51.8° F.). Hanson and Webster (11) observed a feeding period in the pea pod of 19 to 28 days with a maximum period in vetch of 35 days, while Brittain (3) states that 17 to 20 days are spent in the pea pod. Cameron (4) found that the larvae moult 4 times during their development, passing through 5 stadia.

The time necessary for the larvae to complete their development and the total time they may spend in the pod are not always the same. Provided a larva finds plenty of nourishment it may develop rather quickly, but some larvae may remain in the pods for rather lenghty periods. Normally, the larvae appear to require about 3 weeks to 1 month to complete their growth.

Larval Emergence from Pea Pods

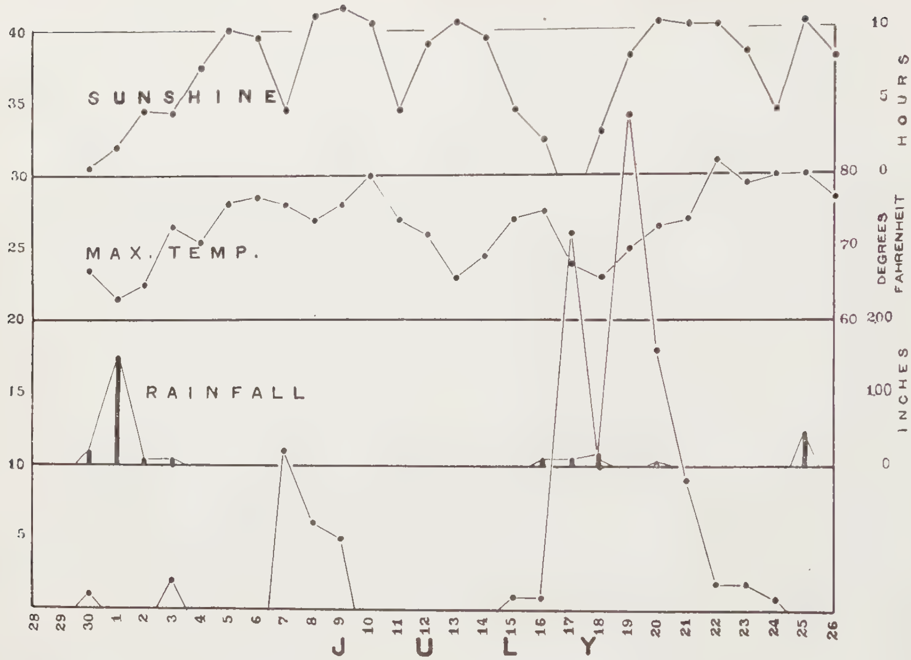
The periods during which the larvae are emerging from the pea pods were found to cover a much longer time than had been previously recorded. In fact it was usually necessary to close down our work for the season before the last of the larvae decided to come out of the pea pods. Thus a few larvae were still emerging by October 1 in 1936, and on October 10 in 1939 and 1941. On these occasions tins of soil were placed under pea hoppers used for emergence studies at the time of our departure and were found to contain a few pea moth cocoons the following spring. However, it was found that the greatest number of larvae usually emerge from the pea pods during the last week of August and the first week of September.

As soon as a larva leaves a pod and drops to the ground it is the common practice for it to try to get out of sight beneath the soil surface as rapidly as possible.

Cocoons

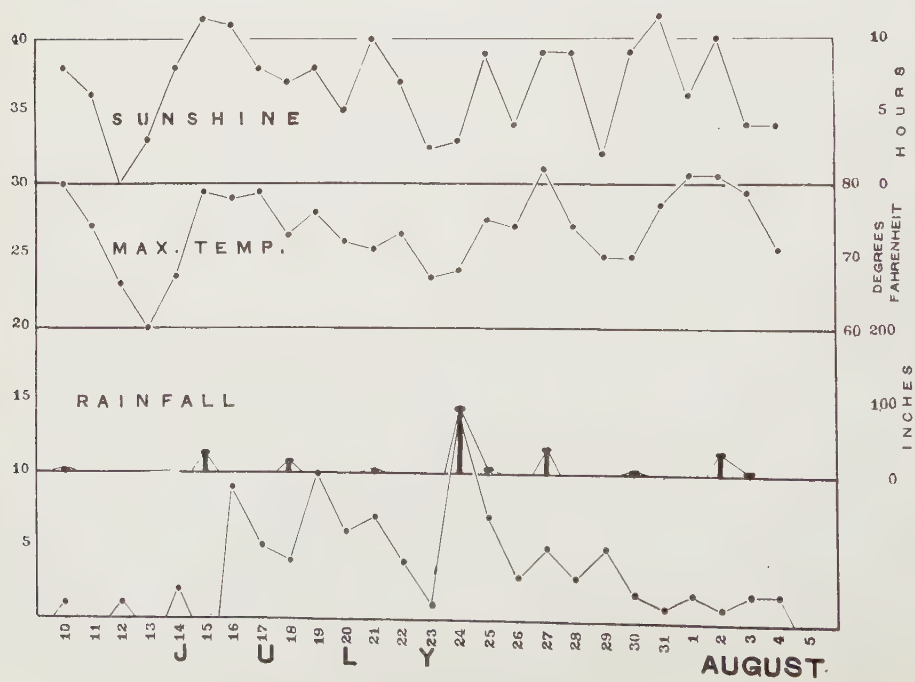
On entering the ground the larvae spin small silken cocoons into which they work soil particles. It has been found that if soil is not available other extraneous material may be made use of or the cocoon may be formed occasionally without the assistance of any foreign material. Normally, however, the cocoon looks like a small lump of earth and it is not easy to distinguish it from the surrounding soil. The pea moth hibernates within this cocoon as a larva and pupation does not occur until the following spring. Thus 9 to 10 months of the year are spent within the cocoons as hibernating larvae.

PEA MOTH EMERGENCE



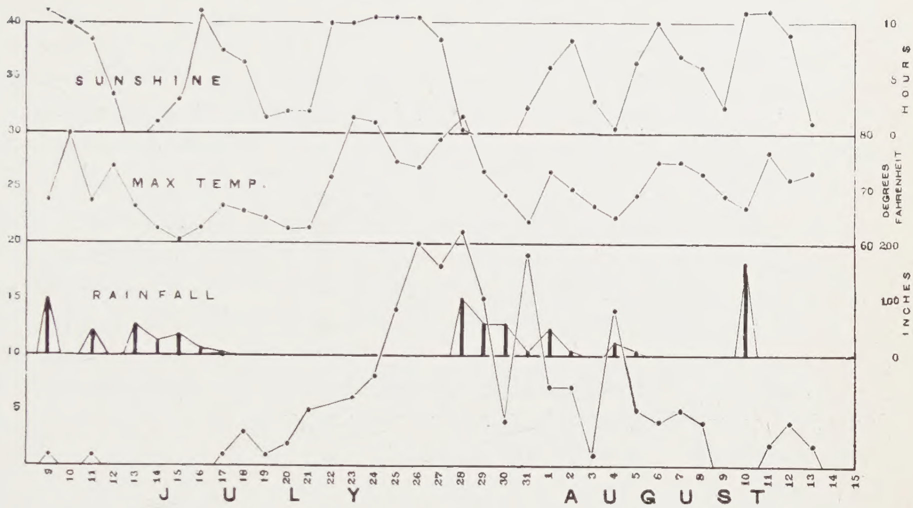
1937

PEA MOTH EMERGENCE



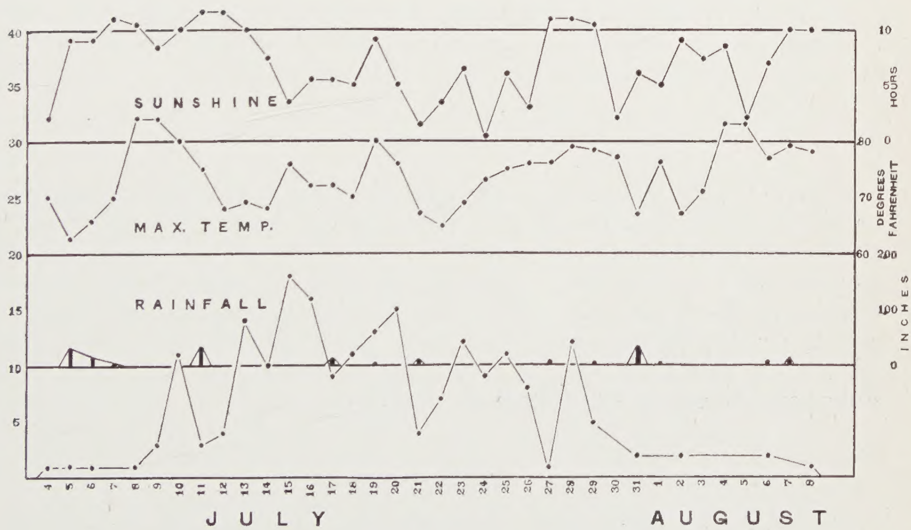
1938

PEA MOTH EMERGENCE



1939

PEA MOTH EMERGENCE



1940

FIGURE 1. Emergence of pea moth in successive years 1937 to 1940. The lower line in each graph shows emergence in percentage.

Pupation

Fluke (9) found pupation taking place on June 15, with the moths emerging 3 to 4 weeks thereafter. Brittain (3) records the first pupa on June 19, 1919, in Nova Scotia with the first adult appearing on July 12. He concluded that the duration of the pupal stage "would seem to be in the neighbourhood of from 3 to 4 weeks." Cameron (4) found that pupation takes place in June and the end of May, and that its duration lasts about 2 weeks.

As might be expected from our knowledge of the length of the period of emergence of pea moth adults, pupae are also sometimes to be found over a rather lengthy period. Thus on the Gaspe coast in 1941 the first pupa was found on June 9 with a peak of pupation apparently being reached on July 10 and the last pupa being found on July 29. The first pupa was not found until June 23 in 1939 and in 1938 the peak of pupation was around June 30. It would appear that the pupation period may be as short as 10 to 14 days and sometimes last as long as 3 weeks.

Second Generation

Working on this continent, Hanson and Webster (11) record the presence of a partial second generation of pea moths. This condition has also been observed by some other workers in Europe. As yet, we have no direct evidence that a second generation occurs on the Gaspe coast. It has been found that if pea moth larvae are allowed to spin up their cocoons in soil in the autumn and then maintained thereafter at room temperature (and sufficient moisture) that most of these larvae will pupate and emerge as moths some time around December of the same year.

SUMMARY

Records of observations on the life history of the pea moth, *Laspeyresia nigricana* (Steph.), in Bonaventure County, Province of Quebec, covering the period of 1936-1942 are presented, and these data are compared with all other available records of the life cycle of the insect made by other workers in North America. The times of adult emergence, preoviposition period, egg laying, egg maturity period, larval development, larval emergence from pea pods, cocoon formation, pupation, etc., are dealt with. Fourteen references to the literature are given.

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BOOK REVIEW.

Modern Poultry Farming by L. M. Hurd. The MacMillan Company, Canada, 1944. (Rural Science Series.) $4.50.

Described in the preface as "a practical guide for both large and small poultry keepers and those interested in starting a poultry enterprise" this text fulfils this purpose to a rather gratifying degree. The difficulty of interpreting the scientific in practical terms which are understandable to a great many people of varying degrees of educational training and outlook is generally well appreciated and the author has produced a very readable book which will be found of value to poultryman, student and poultry specialist.

Illustrative figures are clear and well chosen. In some instances, however, the tabular material chosen seems to be unnecessarily complicated in arrangement, particularly in the chapter dealing with "investment, returns and expenses in poultry farming". The fundamental requirements in starting a poultry enterprise are clearly set forth and lay a firm foundation for the application of the detailed instruction to follow. The choosing of the most suitable breed, housing, incubation, brooding, feeding, management, breeding for egg production, and poultry diseases are all well but briefly handled. Under the above headings several matters are worthy of comment: first, that although excellent detailed plans for brooder houses are shown, laying houses have not been accorded the same treatment to an equally satisfying degree; second, illustrations on the subject of preparing dressed poultry for market are particularly well chosen; third, the very controversial subjects of inheritance of and culling for egg production are perhaps not placed in the proper perspective with regard to the uncertainty of existing recommended practices; and last, the subject of disease is given a very important place in the book, which those who are in a position to know will realize is merited. All in all, the book deals with principles in a thorough and lucid manner giving detail to a sufficient degree, and is well worth careful study by those for whose attention it has been specifically published.

H. S. Gutteridge.